Formation of Large Scale Structures

M.Arnaud (CEA/Sap)

Thanks to X. Barcons

Structure formation in the Universe

z~0

?

z~1100

400 h⁻¹ Mpc

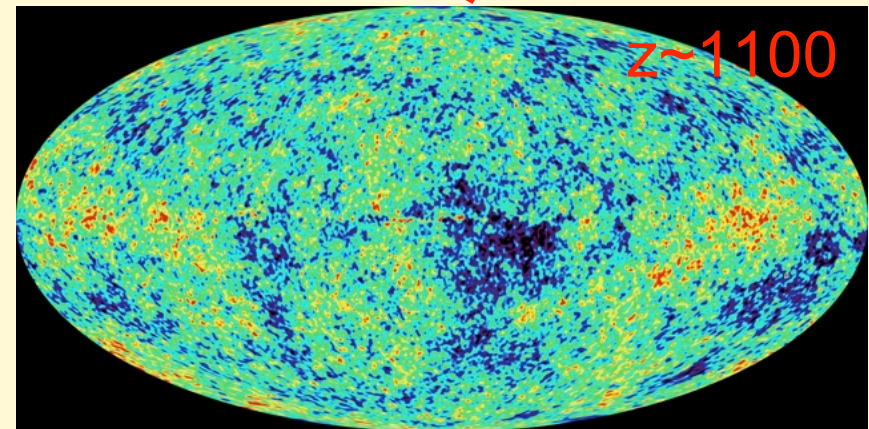200 h⁻¹ Mpc

redshift space
62295 galaxies

SDSS
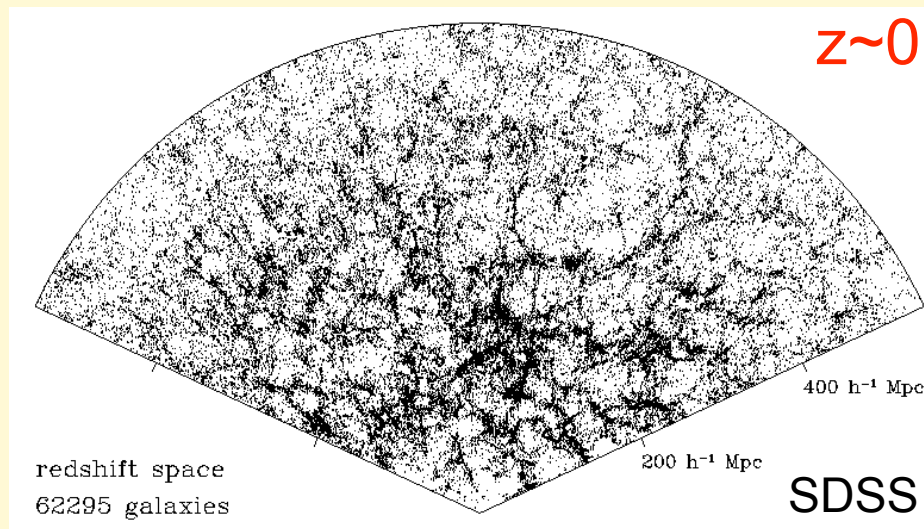
A highly structured Universe
(stars, galaxies, clusters, filaments, voits..)
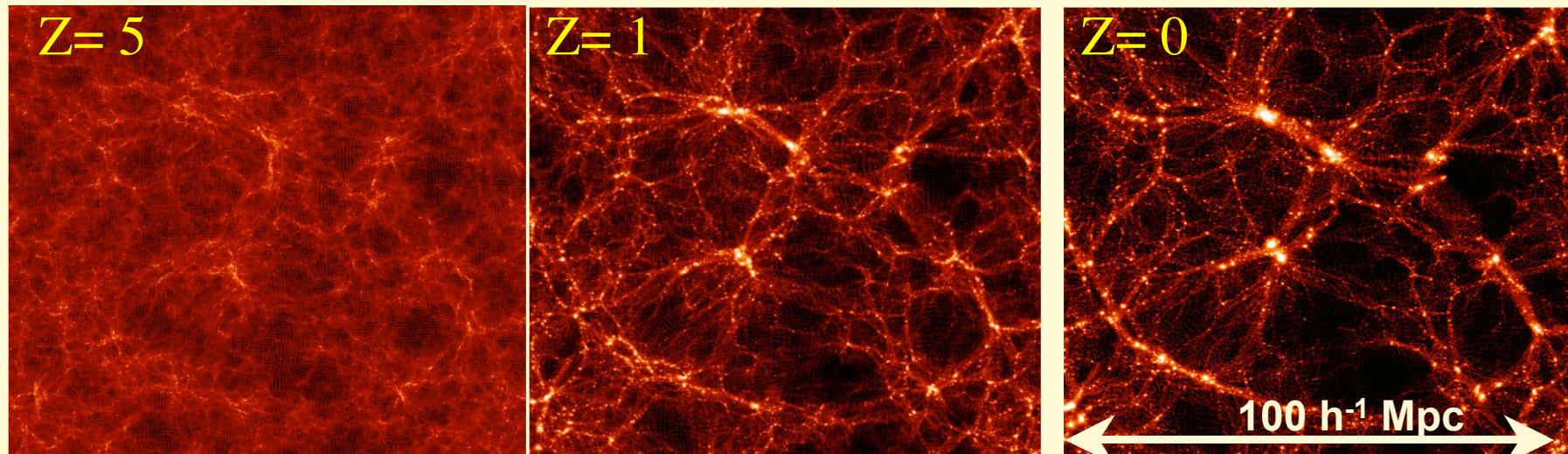
How did structures form and evolve ?

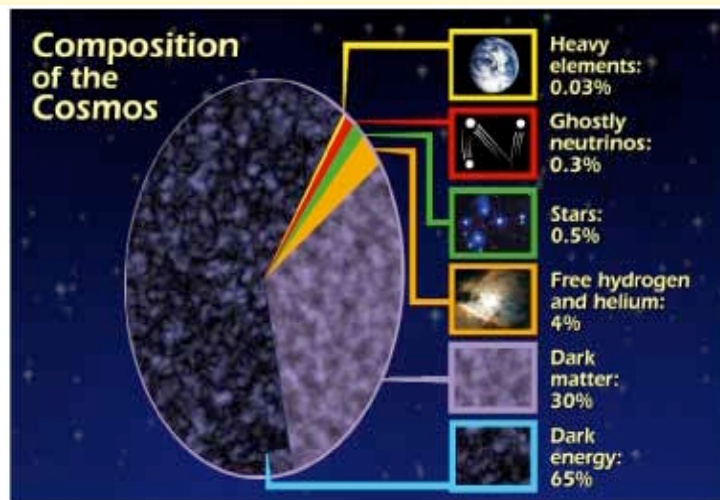from   initial density fluctuations
in the 'given' ΛCDM cosmology.

Boundary conditions known!

Hierarchical model of structure formation

Z = 5   Z = 1   Z = 0

100 h^{-1} Mpc

P(k)+ΛCDM cosmology =>'standard' hierarchical scenario of structure formation

Composition of the Cosmos

Heavy elements: 0.03%

Ghostly neutrinos: 0.3%

Stars: 0.5%

Free hydrogen and helium: 4%

Dark matter: 30%

Dark energy: 65%

X-ray observations to study:

• The clusters of galaxies (DM + hot gas)
The largest 'virialized' mass concentrations
from z ~ 2 till now

• The warm/hot filaments since z ~ 1-2

- The hierarchical (Cold) Dark Matter clustering: ~ understood

  - universal cluster mass profiles at z~0 as predicted

  - cluster dynamical state and evolution (mergers/sub-structures) as expected

   …. But still a problem with DM halos in galaxies

- The history of (cold)/hot/warm baryons: NOT understood

    incl

  - The fate of ~ 50% of the baryons since z~2

  - The ICM entropy 'excess' in nearby clusters

  - The cooling core properties

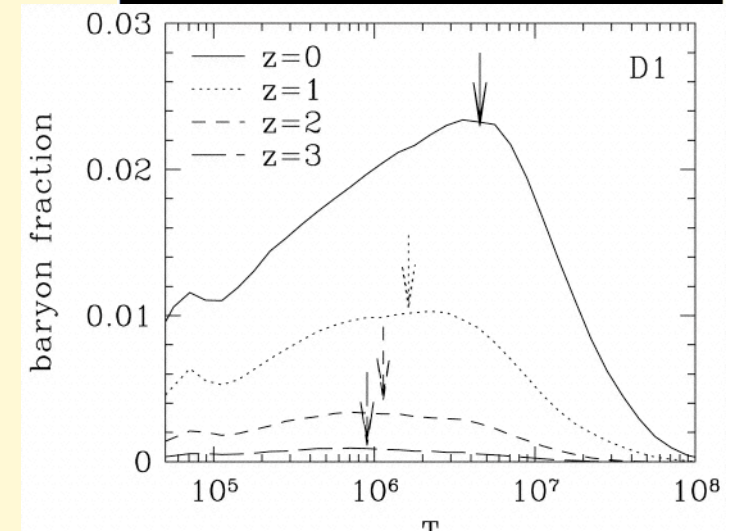 - non-thermal component (B, relativistic part.) in the ICM

The 'missing' baryons and the WHIM

- BBN + CMB: $\Omega_b = (4.6 \pm 0.4)\%$.

  - $z > 2$, Damped-Ly-α pop. + Ly-α clouds

  - $z < 2$, Ly α abs. + galaxies + clusters = $(2.5 \pm 0.3)\%$.

    ~ 50% of the baryons are 'missing'
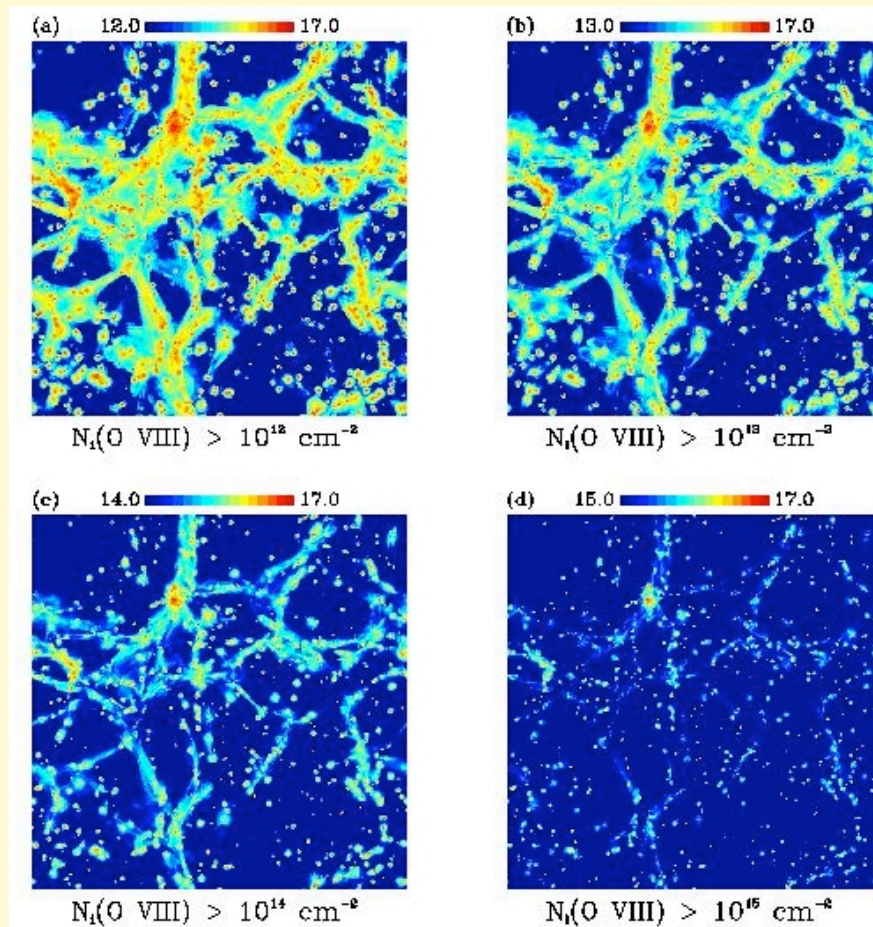
- In WHIM (filaments) at low z ?
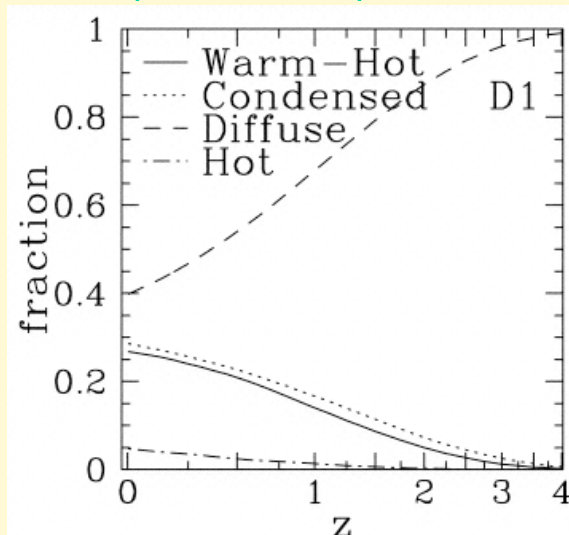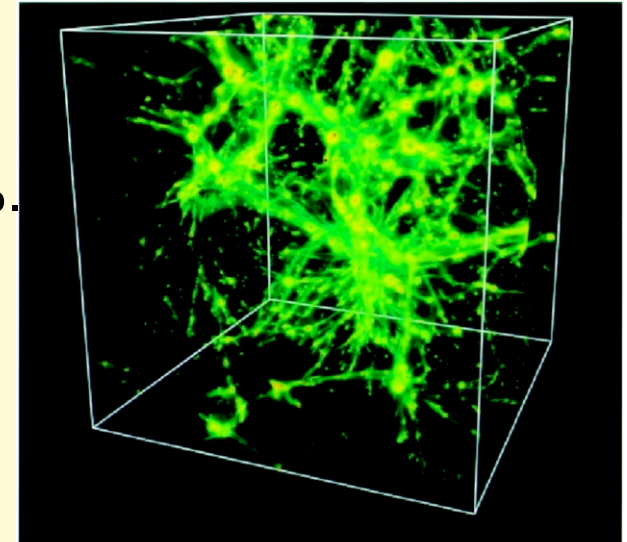
[Dave etal. 2001]

- IGM hotter towards low z due to shock heating
- Extra heating might be present due to SF & AGNs
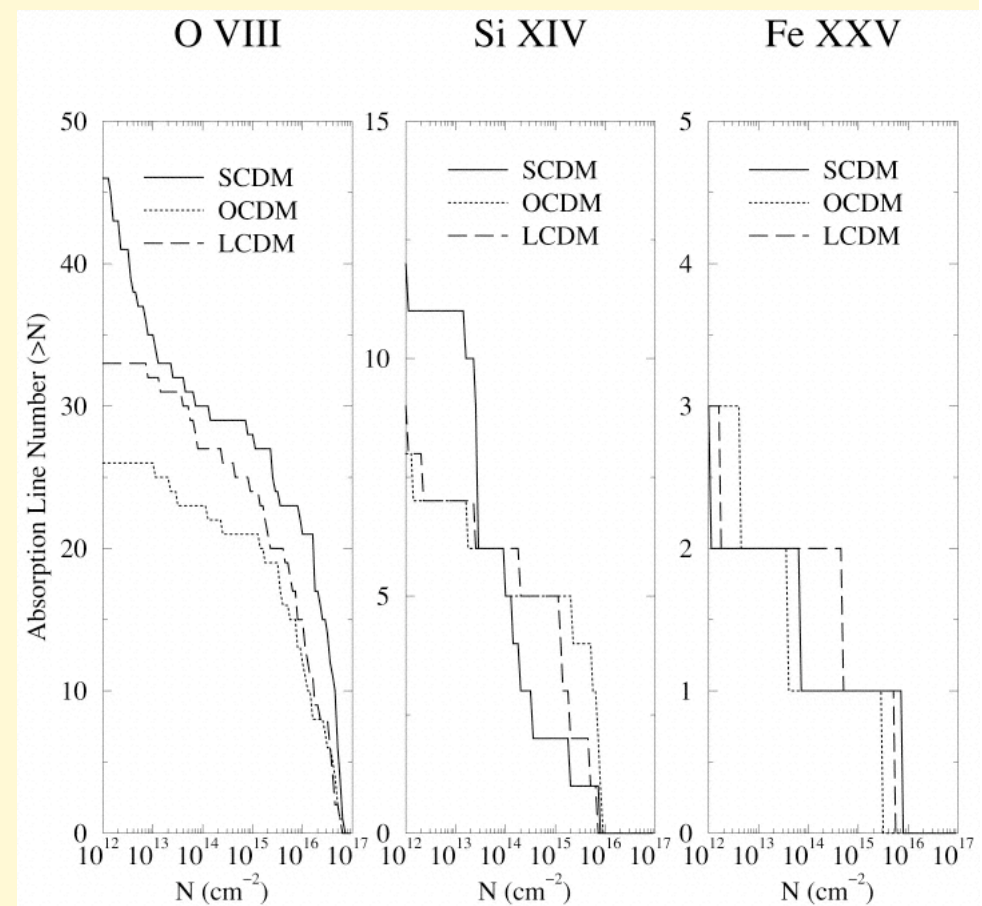
Large fraction of baryons at $T \sim 10^5 - 10^7$ K

Detect (started) and study properties ($d\mathcal{N}/dzdN$, temperature, metallicity) versus z
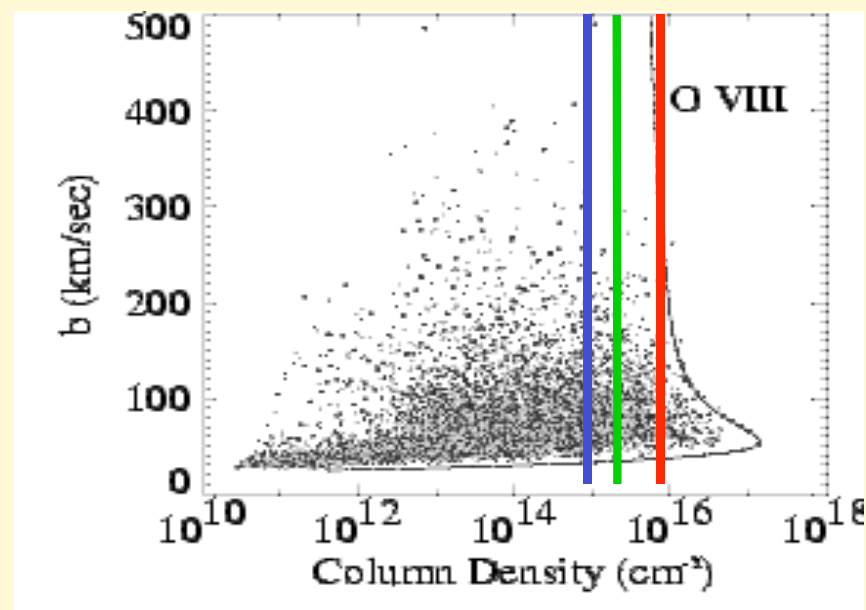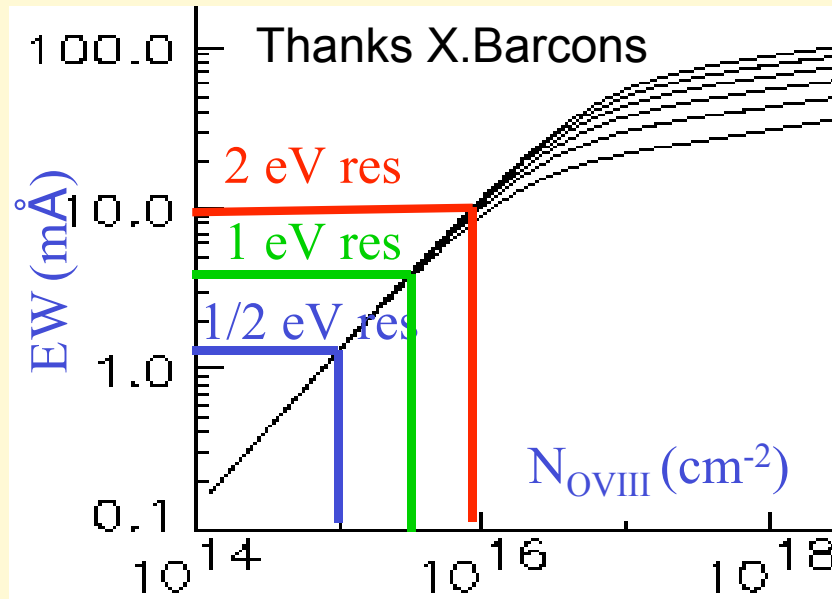Probe LSS/galaxy formation

[Fang, Bryan & Canizares 2002]

[Fang & Canizares 2002]

Column densities

Distributions of absorbers

Using absorption lines in X-ray

Mission requirements

Thanks X.Barcons

2 eV res
1 eV res
1/2 eV res

EW (mÅ)

N_{OVIII} (cm^{-2})

O VIII

b (km/sec)

Column Density (cm^2)

$$(S/N) \sim 50 \times [(S_{eff}/10 \text{ m}^2)QE\, t/(100 \text{ ks})\, S/(10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1})]^{1/2}\Delta^{-1} \text{ (eV)}$$

Sensitivity (EW) $\sim \Delta/10$

Cryo imaging spect

Gratings

$\Delta \sim 1$ eV

Shorter exposures

Higher z

$\Delta \sim 0.1$ eV

Weaker absorbers

QE~0.5-1

Broader sampling

QE ~ 0.03

More detailed sampling

The structure formation: Beyond gravity
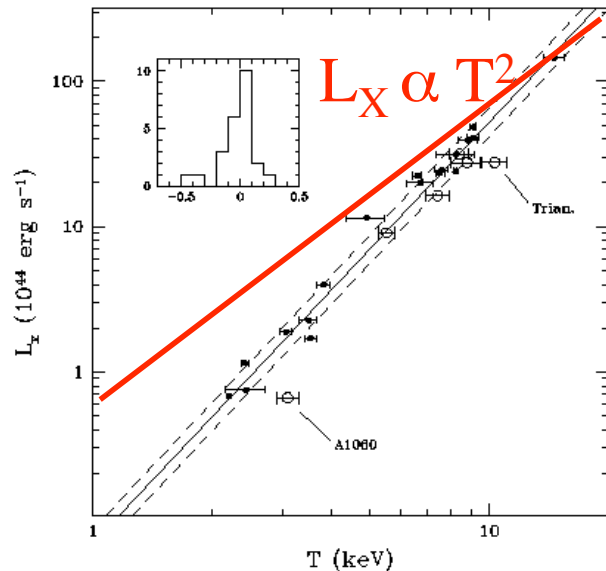

[Jones et al, 03]

[Ritchie & Thomas, 2002]
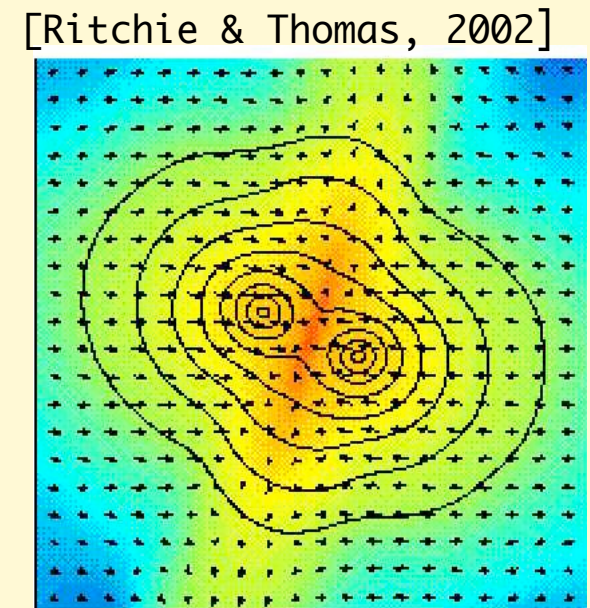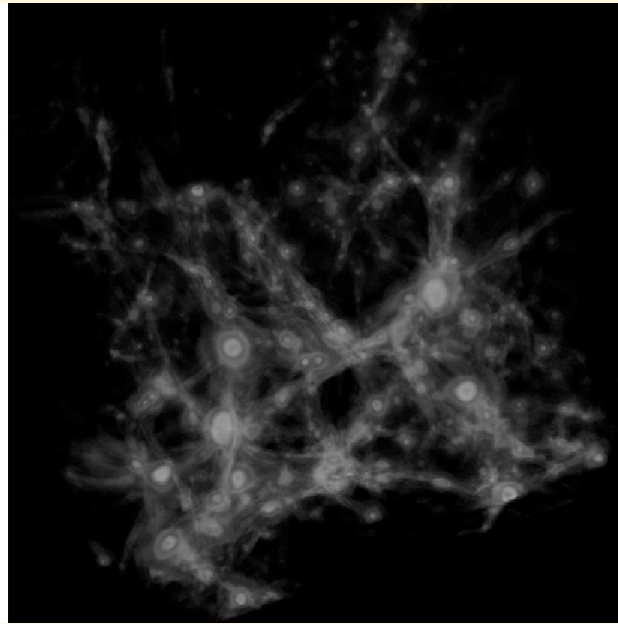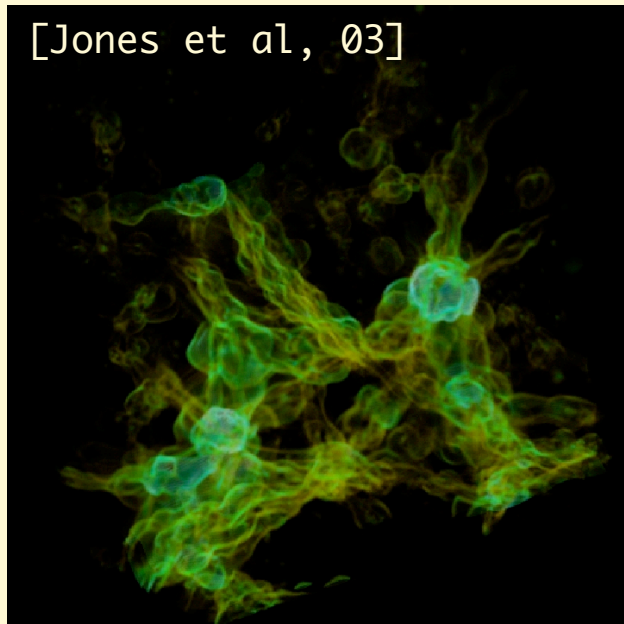
Bayons history: first driven by gravity

Gas "follows" Dark Matter ; grav. heating in potential wells
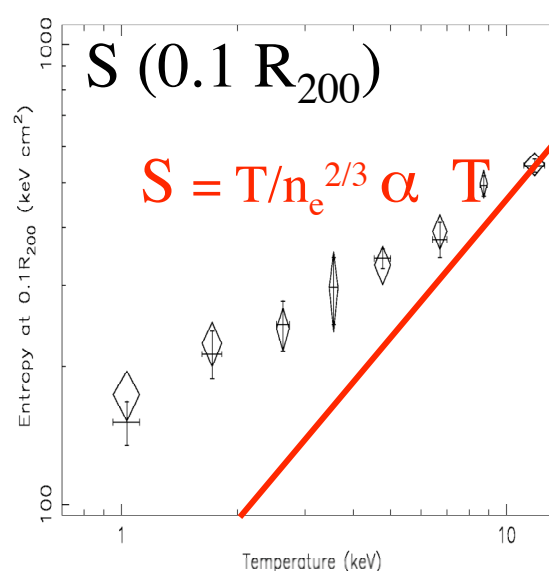
BUT gravity alone cannot explain:

• Star/galaxy formation !

==> cooling; pb: over-cooling; wrong LF, SFR(z) ==> + feedback?

• Entropy of ICM in *present day* clusters and deviation from 'standard' scaling laws.
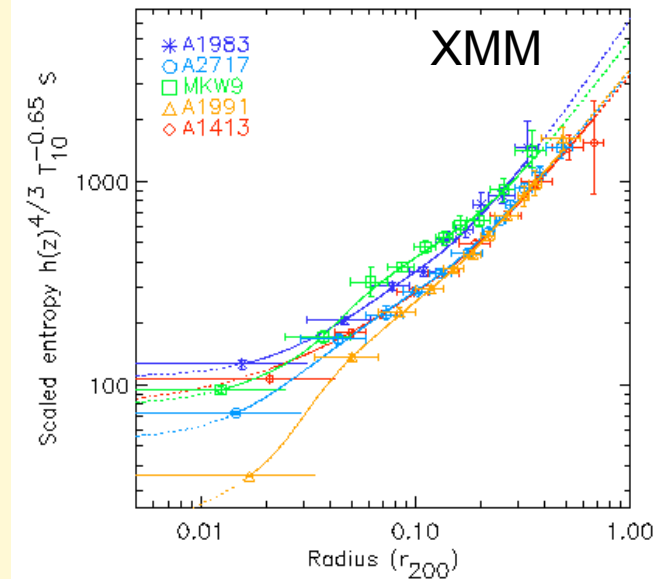
The excess entropy in nearby clusters

$L_X \alpha\ T^2$

$S\ (0.1\ R_{200})$

$S = T/n_e^{2/3}\ \alpha\ T$

XMM

*A1983
*A2717
*MKW9
*A1991
*A1413

[Arnaud & Evrard 99]

[Ponman et al, 03]

[Pratt & Arnaud, 03, 04]

Entropy excess / pure grav. heating
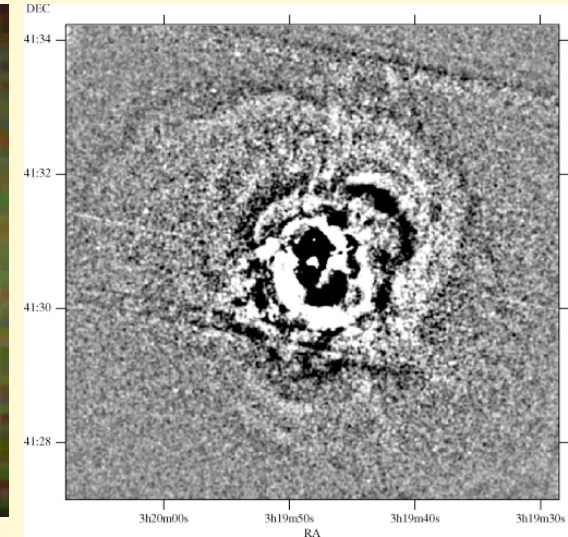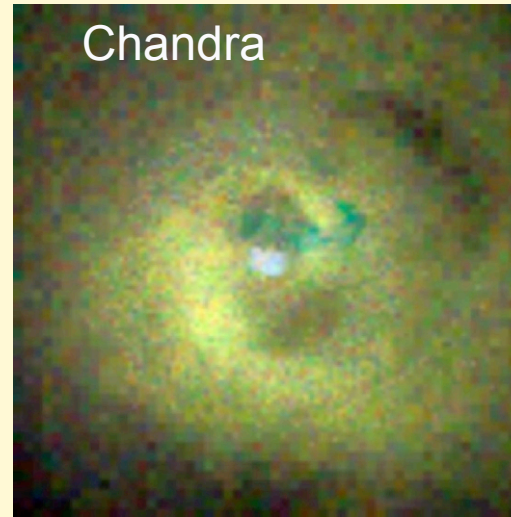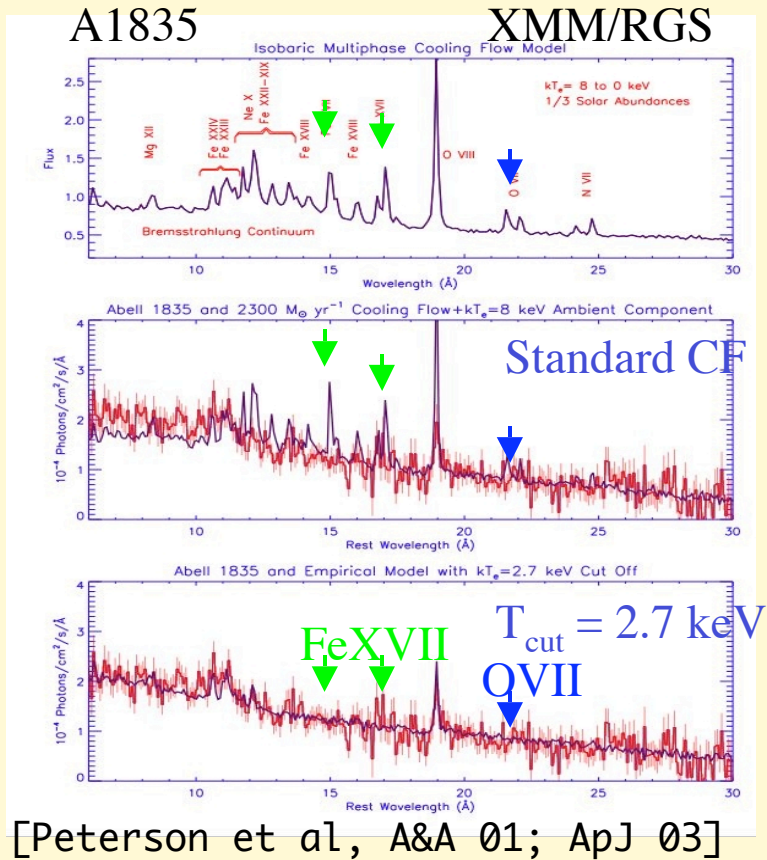Relatively more in low mass systems

Self-similar entropy profiles
=> Not simple 'pre-heating'

Current ideas: gas history depends on grav heating

PLUS cooling and SN and/or AGN heating (and ?)

Processes not understood

The cluster core

A1835 XMM/RGS

Standard CF

$T_{cut} = 2.7$ keV

FeXVII OVII

[Peterson et al, A&A 01; ApJ 03]

Chandra

[Fabian et al, 00,03]

Core properties not understood ! Balance between cooling and AGN heating?
effect of conduction, turbulent mixing ?

A laboratory to understand galaxy formation and ICM cooling/AGN heating

Key observations to understand ICM thermo-dynamical history

1) Entropy (profiles) versus z (and mass)

=> disentangle role of various processes
cooling, SN/AGN heating affect S :
≠ level and ≠ time scale

1bis) Abundances versus z
   integral measure of SN activity

2) Spatially resolved spec. of cluster core
    at high spectral resolution

3) Non-thermal energy
    - residual kinetic energy
    - turbulence
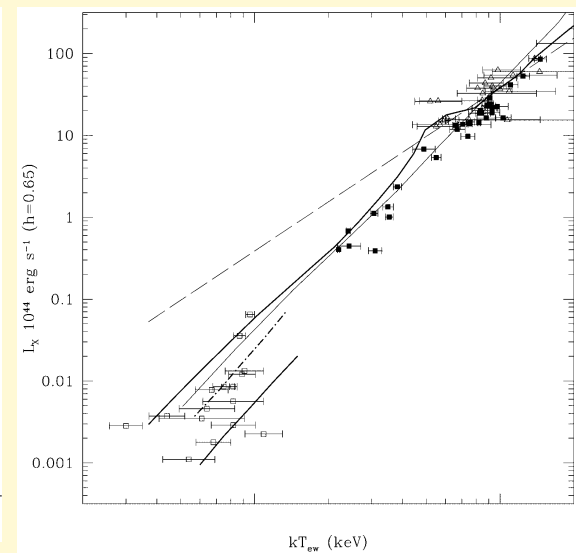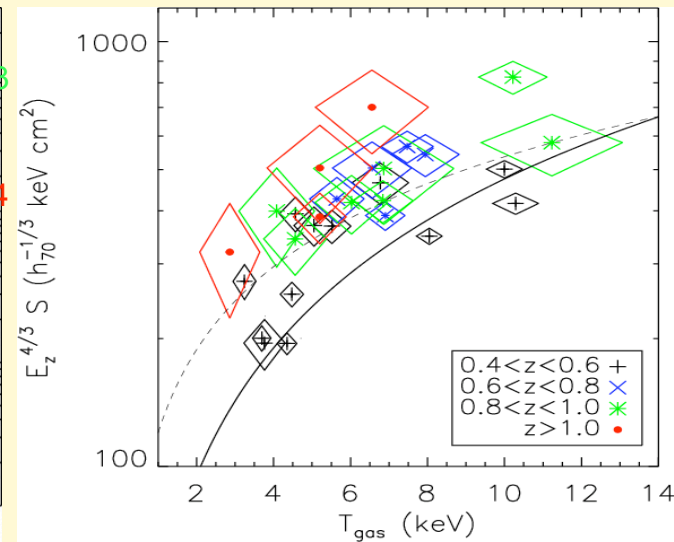   - high E particles injection/acceleration
    - magnetic field

NB: same information needed
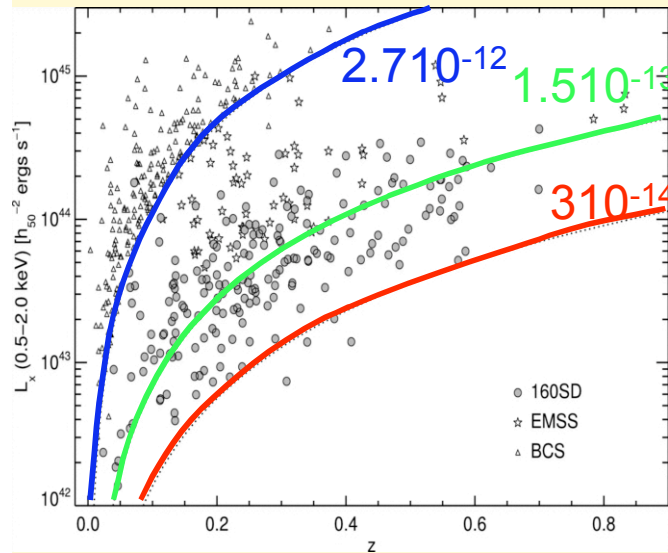

mergers

[Cavaliere et al, 1999]

• entropy excess > in low mass
• low mass systems seeds and building blocks of today massive clusters

• verify 'standard' model of Dark Matter collapse
• for 'precise' cosmology with clusters ……..
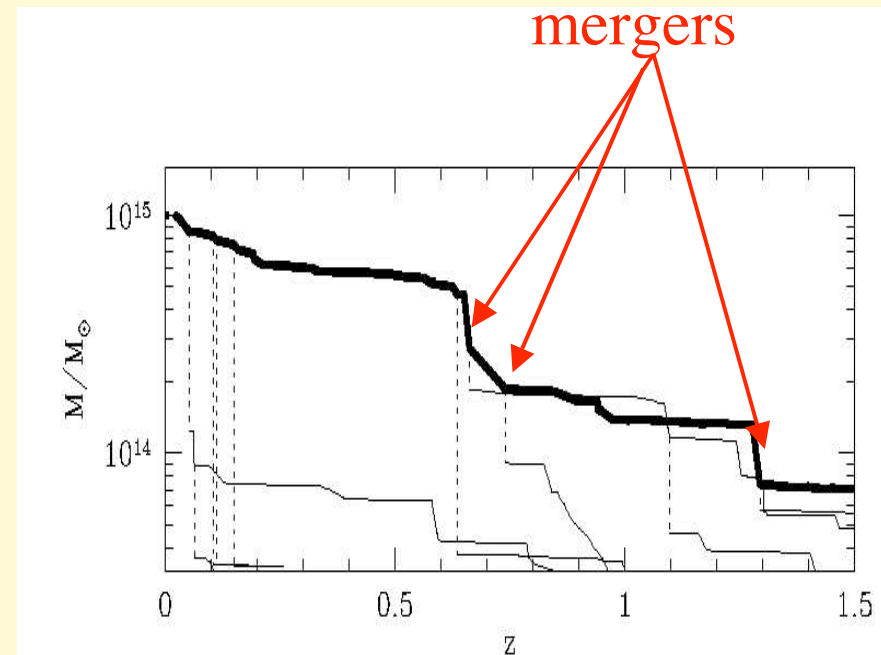
The (z,Mass) range: proposed strategy

Present evolution study: highly incomplete

Global properties z > 0.5 ; kT > 4-5 keV

z > 1: basically unknown

Strategy:

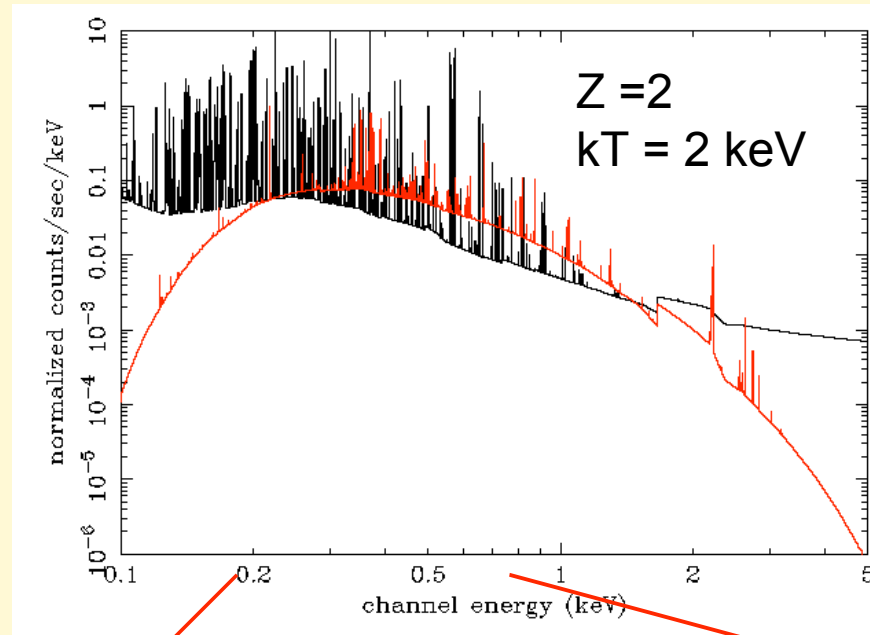**Pb:** 5 orders of magnitude in Lx !
Sx α $(1+z)^4$ ~ 100 at z=2

Unrealistic:
   extend to the full z-Lx plane

• Detailed study of kT > 2 keV (regular cluster population) up to z =1 (spec. kT < 5 keV)
• Global cluster properties up to z=2 => req. driver (abundances)
• Detect groups down to z=2 (NB properties highly uncertain)
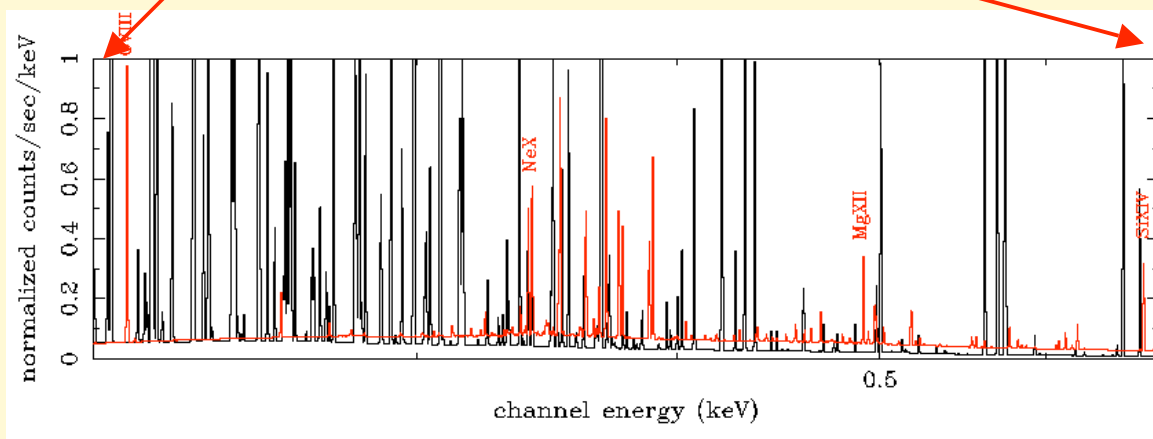
Mission Requirements

Z = 2
kT = 2 keV

Energy range: 0.2 - 10 keV

- detect OVII up to z=2 (0.218 keV)
- 10 keV for kT estimates
- *80 keV for hard tail study (rel part/B)*

Spectral resolution: 2 eV below 1 keV
- separate cluster lines and sky line and be photon limited for α elements line z=0.5 - 2
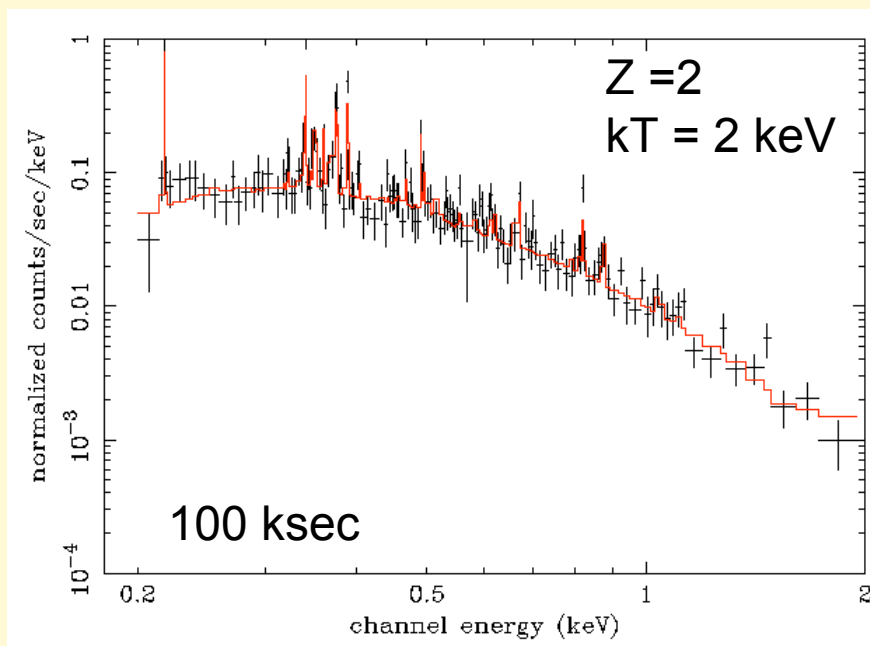- *turbulence study*

Effective area: 10m^2@ 1 keV

5 σ detection in 100 ksec of Mg line kT > 2 keV z <2

L_{bol} = 5.3 10^{43} ergs/s ; 50% flux in extraction region (r<15")

Science Feasability checks
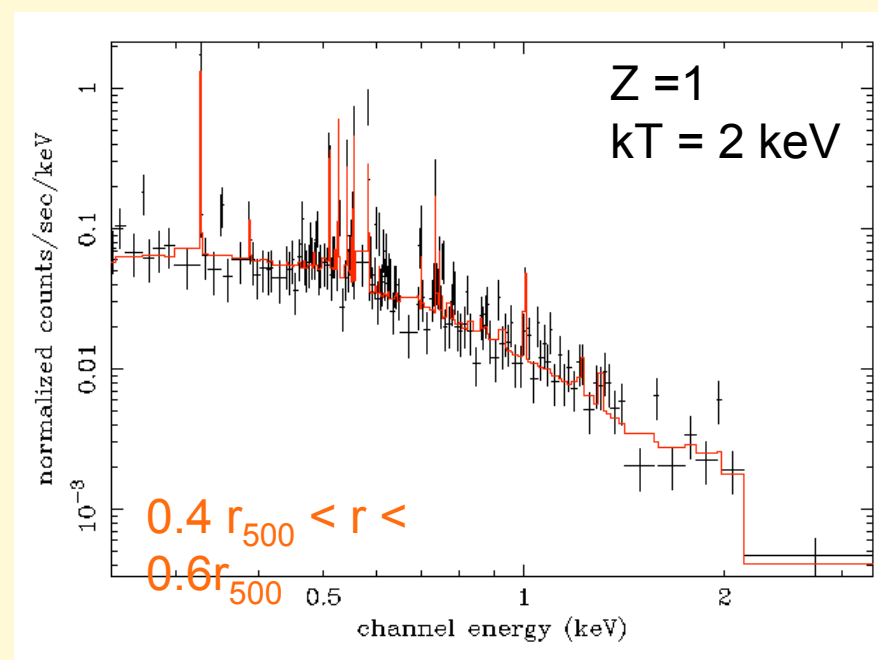

Z =2
kT = 2 keV

100 ksec

Z =1
kT = 2 keV

$0.4\, r_{500} < r < 0.6 r_{500}$

kT : ± 2.7% (1σ); Redshift!
O: ±20%; ±25% Ne,Mg,Si; ±11% Fe

Global properties up to z=2, kT> 2keV
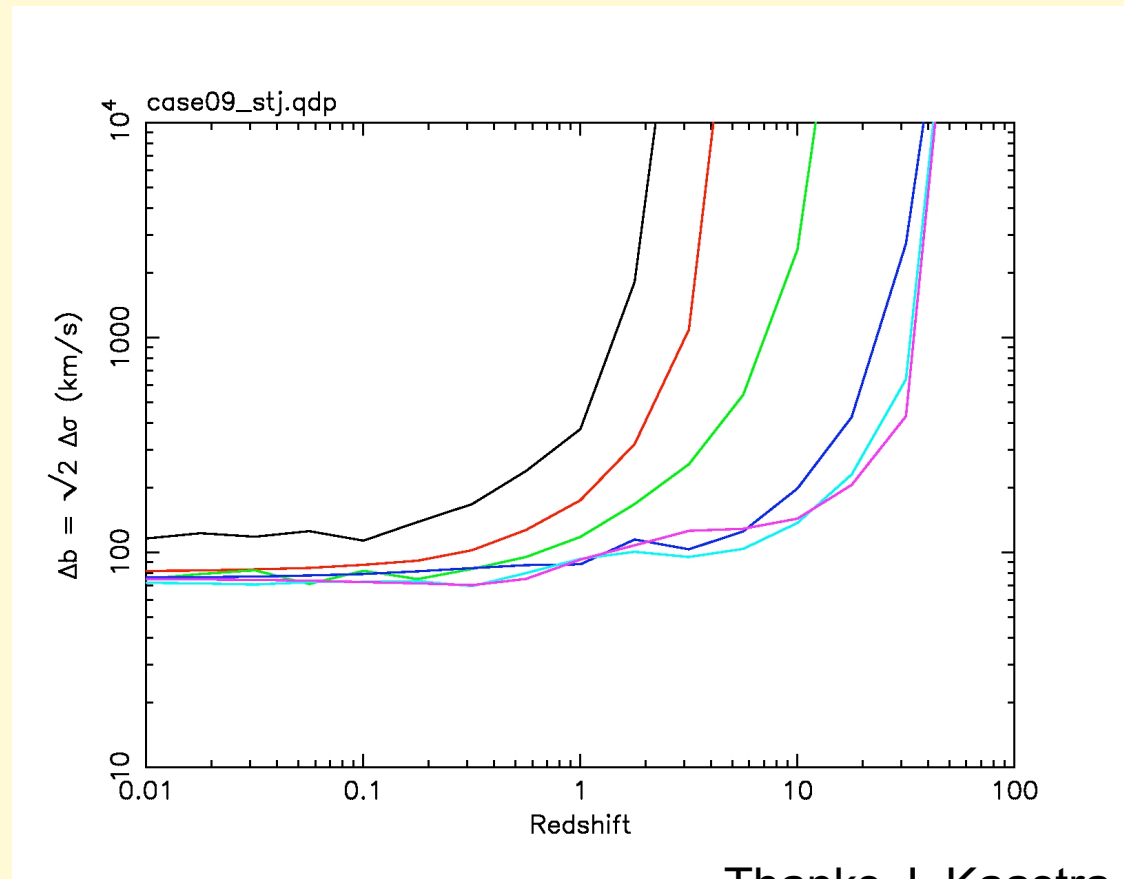
kT : ± 3.5% (1σ); ± 5.5% with CCD

kT profiles ==> S (r) and M(r)
As in local Universe with XMM/Chandra

Serendipitous search of 'first' groups: with CCD camera
kT=1keV, z=2, $N_H=1.310^{20}$, 1/2 flux in 15" radius
=> 7.5 10^{42} erg/s; S[0.2-2] = 1.210^{-16} in 100 ksec (5 σ detection)
brightest 1 keV group at z=0

Thanks J. Kaastra

Measure turbulence

R$_{500}$

kT = 2 keV
Z=0.8
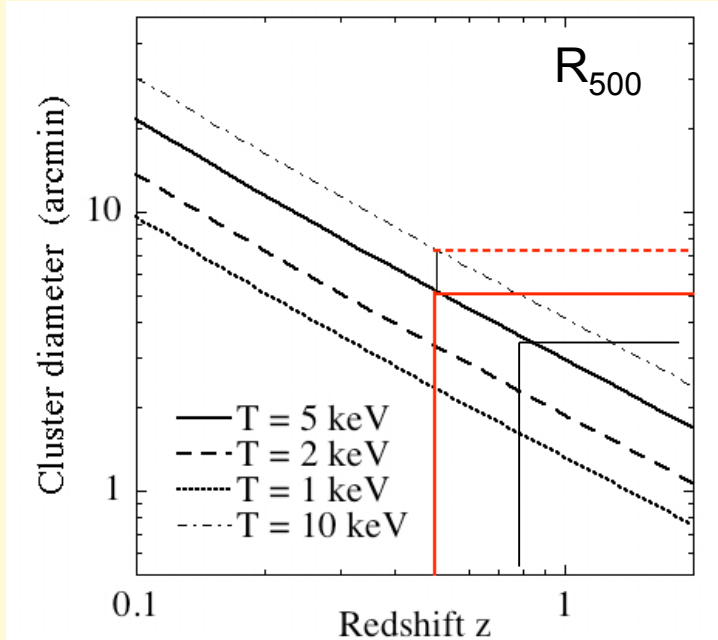
Field of View

1) *Cluster coverage:*

Φ = 5' for a 5keV cluster at z=0.5
   7' for 10 keV
Need estimate bkg
   => Φ ~ 7' for CCD camera
Need cryo-spectro z> ~0.8 for Ab
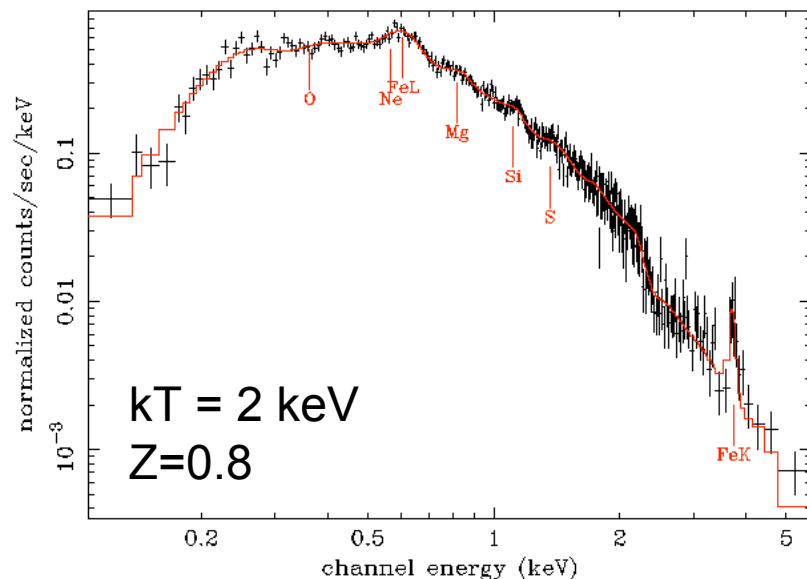   => Φ ~ 1.7' for NFI (0.5 r$_{500}$, 5keV)
also needed for 'nearby' Cooling Core

2) *Cluster search at z > 1*

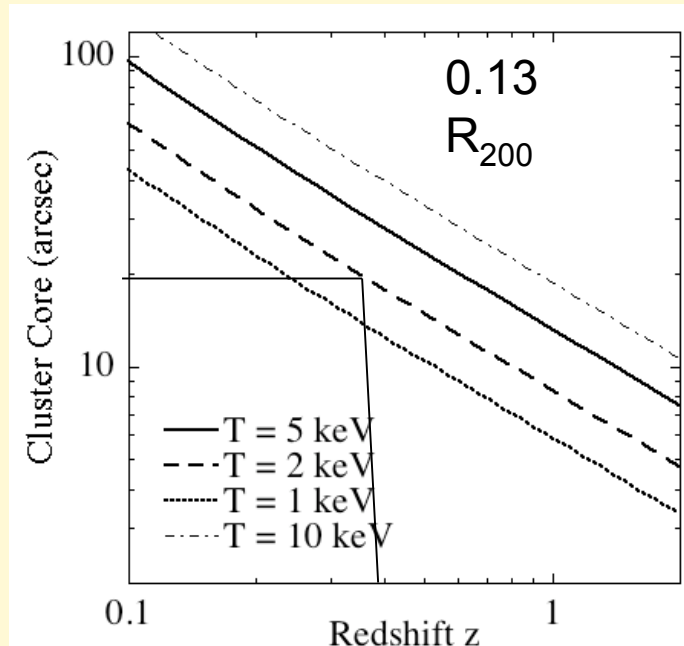Study clusters beyond XMM detection limit (2
   orders magnitude in S$_{eff}$)

N(1<z<2, kT > 2 keV) = 7.4 /deg2
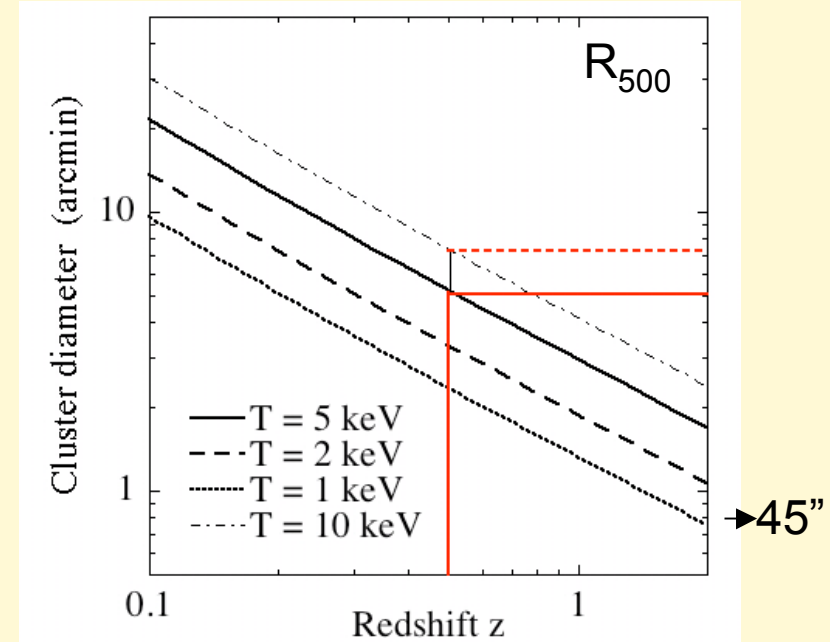   or 0.05 per 5'X5'
1 /5 pointing ==> 10'X 10' (WFI)

Mission Requirements (Cont.)

Core size kT=2 keV; z=2 : 5”
But: to limit AGN confusion : 2”

Fine mapping of CF at z~0.4-0.5

Resolve 1 keV , z=2 cluster:
20” in CCD outer FOV

Spatial resolution : requirement ~ 5” ; 20” outer FOV
Goal ~ 2”

Summary

How structures formed and evolved?

- Boundary conditions ~ known

- General scenario and Dark matter collapse (at least down cluster scale) ~ understood

- Visible matter (baryons) physics NOT understood.

   fondamentally a multi-scale problem: history of galaxies and hot/warm diffuse gas linked

   probably a complex interplay between grav. and non grav physics

ConX/XEUS goal:

Understand the thermo-dynamical history of the hot ICM and the WHIGM

- Fate of 'missing' baryons
- What produces the ICM entropy ?

   grav heating versus cooling/galaxy feedback, any other process

- What limits (regulate) cooling ?
- How and when galaxy feedback worked ?
- Non thermal energy and relativistic particles injection/acceleration

Mission Requirements:

Main drivers: go to high z *and* low mass

Effective area: 10m²@ 1 keV

$\Delta E = 2$ eV below 1 keV ; < for WHIM

FOV : $\Phi \sim 7$' (CCD) $\Phi \sim 1.7$' (high re spec.)

$\Delta \Theta \sim 5$''